PAM 624.139 : 621.643

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Zhukov

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Modern methods of designing, constructing and operating sanitary engineering utilities in permafrost regions were first based upon standard construction practice. Minor changes and additions concerning design and construction details were introduced, but the principal arrangement was maintained with almost no changes.

The operation of the steam pipeline system for heating buildings at the Oymyakon Airport (Eastern Section of Yakut) is a typical example confirming the unreliability of the simple mechanical application of standard construction methods for sanitary engineering utilities in permafrost regions.

The design of the steam pipeline system provided for heating of all airport facilities with one central boiler. The steam pipeline was laid on the ground in insulated boxes which were filled with soil from above. The services to the buildings were protected by thermal insulation. In the course of a short period of time during the first winter of operation, ice blockages formed continuously at different points in the steam pipeline and were removed daily by repairmen. The system was completely out of commission by November. The waste of a great deal of time by repairmen and residents living in the houses necessitated the abandonment of the continuous maintenance of the steam heating system and the conversion to stove heating.

The above example is a case in which the entire capital expenditure on the construction of a central heating system is lost. This occurred not because of an error in the design (the design was worked out on the basis of general normative

instructions) and not because of the unskilful operation of a steam pipeline system under extremely severe climatic conditions, but chiefly because of erroneous attempts to mechanically apply construction experience gained in the central regions of the U.S.S.R. to permafrost regions.

Additions and changes were introduced into the design and construction of later installations as more experience was gained and as further studies of the special features inherent in operating sanitary engineering utilities in permafrost regions were made. These additions and changes were based mainly on installations designed in accordance with standard rules for utilities which must function normally under the following conditions:

a. In the presence of below-freezing temperatures of the ground surrounding the pipelines;

b. In the presence of ice-bearing frozen material under the pipeline which is subject to settlement and loss of stability when thawing takes place.

Measures for ensuring the trouble-free operation of sanitary engineering systems in permafrost regions were basically the following:

1. Raising of the temperature (heating) of the fluid flowing in the pipes to prevent it from freezing;
2. Placing of thermal insulation around the pipes to maintain the material under the pipes in a frozen state;
3. Increasing the bearing capacity of the material under the pipes.

Even when the above measures are taken in the usual manner, freezing of the fluid in certain isolated sections (and hence the disruption of the normal operation of the entire pipeline) can still occur.

Furthermore, the possibility of the frozen material under the pipeline thawing at an isolated point cannot be excluded; this could result in the deformation of the pipeline and the throwing of the entire utility system out of commission. When the pipeline is in a damaged condition, adjacent buildings are often adversely affected. The greatest deformations of buildings are due to sanitary engineering utilities being in an unsatisfactory condition. Thus certain buildings in Vorkut, in Norilsk and in other regions have settled at points where steam pipeline services enter them, near cesspits, etc.

Thus, if the design is not worked out in detail, trouble in the operation of pipelines installed in permafrost regions can occur owing to long lengths of pipelines, the presence of sections with different frost and geological conditions along the route, and different degrees of cooling of the pipelines.

The carrying-out of the above precautionary measures during the laying of pipelines in frozen material increases their installation cost; this incremental cost is an important percentage of the total estimated cost. Furthermore, the operating cost is increased because of the necessity of periodic repair work, of restoring insulation, of ensuring that the pipelines operate properly, etc.

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On the basis of the investigation of various types of pipeline installations in permafrost regions, it is evident that in the majority of cases the application of standard construction methods significantly increases the cost of the installation and sometimes, as at Oymyakon in the above example, leads to useless expenditure and does not eliminate the possibility of troubles. New principles must be sought so that our engineering development and achievements are effectively employed in solving the problems concerned with the installation of sanitary engineering utilities.

The above remarks apply to an equal degree to both heating utilities and water distribution and sewage collection systems. While it is true that water lines and especially sewer lines affect the stability of buildings to a lesser degree than heating mains, and are displaced less frequently, it is also true that reliable solutions to the problem concerned with their installation have still not been found.

The special features of the construction and operation of pipelines in permafrost regions will be briefly examined. When communities, settlements and industrial works are constructed, the installation of pipeline systems with numerous branches and small, discontinuous fluid discharges are generally envisaged. Ice blockages which are difficult to remove can form when fluid motion in pipelines laid in frozen media ceases. In order to prevent pipeline troubles, a specialized brigade must work continuously and additional heat must be supplied for heating the water distribution and sewage collection systems because of large heat losses to the exterior;

the latter losses constitute a significant percentage (sometimes from 50 to 80 percent) of the usefully-expended heat.

An increase in the cost of heat energy in comparison with common standards is also a feature of operating pipelines in permafrost regions. The fluid in water distribution pipes is heated not only during the winter but also during the summer (when the soil surrounding the pipe is at temperatures below the freezing point throughout the entire year).

The degree of the danger of water freezing in a pipe depends not only on the time of year but also on the depth to which each length of pipe is laid, because of the fact that the ground temperature lags behind the fluctuating air temperature.

All this results in complicated operating conditions for the entire pipeline system and necessitates continuous control of the utility system which is seldom carried out in modern times.

Instead of effective preventive systems of control for utility systems, operators generally make passive observations and wait for signals of troubles upon which the system must be immediately repaired and restored. Such a "method of control" is often the cause of large deformations of adjacent installations; indeed, these deformations often serve as signals of the locations of troubles in pipelines. Large design safety factors are frequently used with respect to pipeline operation so that fluid freezing is eliminated and trouble-free operation of the pipelines is guaranteed.

New methods of installing and operating sanitary engineering utilities in permafrost regions are set forth below in the order in

which it is proposed they be considered.

Proposed Central Heating Systems

Considering the difficulties of protecting buildings built on frozen foundation material from damage due to adjacent steam or hot water pipelines and the large pipeline heat losses which increase the consumption of thermal energy, it is proposed that central heating plants deliver not steam or hot water but electricity * or gas.

When thermal energy is transported via electrical or gas conduits, energy transfer problems are simplified, heat losses in mains are eliminated, thermal effects of conduits on adjacent structures are prevented, and capital expenditures on conduit installations are considerably reduced.

A steam conduit cannot be extended more than from 1 to 2 kilometers from a central boiler, in practice, as a further increase in its length would result in consumers being supplied with condensate instead of steam and cold water instead of hot water. In other words, all the transferable heat of the water is removed by conduit heat losses.

Remote consumers must be serviced by a second boiler-house situated closer to them, whereas the operational radius of a thermal station is increased to several tens of kilometers when

* The author, while taking into account the existing situation concerning the cost of electrical energy, refers his proposal to the near future when the cost of electrical energy will be significantly reduced.

electrical conduits are installed. As an example, it can be shown that the community of Yakutsk, which consumes its annual fuel supply in a variety of ways, could pipe gas from the Kangalas coal deposit situated from 40 to 45 kilometers from Yakutsk. It is difficult to express heat consumption figures for Yakutsk, but the fact that the danger of deformation caused by the thawing of foundation material is less when gas conduits are installed cannot be questioned.

Concrete numerical data for each region would be required to compare the economic efficiency of electrical conduits versus steam pipelines with respect to installation and operation. The cost of operation also varies with its amplitude and with other concrete factors which cannot be considered in this article.

The table given below presents characteristics and comparisons of advantages and disadvantages of existing and proposed methods of constructing thermal stations.

This comparison does not exhaust all advantages and disadvantages of both types of central heating systems. Only the principal and most essential advantages and disadvantages are listed. The comparison shows the advantages of electrical conduits and gas pipelines.

The thermal interconnection between the principal features of the examined utility systems and the frozen foundations of installations are apparent. This interconnection has an effect on the stability of structures and can be the cause of large deformations of structures. While it is true that it is possible

to reduce the thermal influence of central heating pipes on a building by correctly designing the heating system of a populated center, it must also be acknowledged that such designs have not yet been prepared with a degree of accuracy sufficient for permafrost regions and that new methods of heating communities and settlements must therefore be proposed.

Table

Comparative Data on Different Methods of Constructing Central Heating Systems

No.	Steam or Hot Water Pipelines	Electrical Conduits or Gas Pipelines
1.	A boiler-house with simple equipment and servicing personnel with average qualifications is required.	A thermal station (or gas plant) with complex equipment and highly-qualified servicing personnel is required.
2.	Servicing a large area requires several boiler-houses (within blocks and inside buildings) with a large staff.	Only one thermal station (or one gas plant) with a reduced staff is required to service a large area
3.	Additional boiler-houses must be constructed to service a new settlement (community) near the old one.	The original thermal station (gas plant) is used, enlarged if necessary to service a new settlement (community).
4.	A boiler-house is located in the center of the consumers; this sometimes results in it being built under unfavorable frost and geological conditions. An access route to the boiler-house and transportation facilities are provided.	A thermal station (gas plant) is constructed near the source of fuel on a stable foundation and with reduced expenditures for transportation facilities, because of the feasability of selecting the most favorable location.
5.	High-quality fuel is necessary to obtain an effective coefficient of efficiency in a standard boiler-house.	Thermal stations generally rely on the use of poorer-quality fuels and waste materials.

	Steam or Hot Water Pipelines	Electrical Conduits or Gas Pipelines
6.	Steam pipelines are characterized by large heat losses.	The losses from electrical conduits and gas pipelines are negligible.
7.	If isolated consumers are situated at a great distance from a boiler-house or from one another, it is difficult (or costly) to provide them with steam because of large heat losses in the supply lines.	Small numbers of isolated consumers can be provided with heat without large losses and expenditures, and almost irrespective of their location in relation to the thermal station. Expenditures in this connection are in terms of supply line costs.
8.	Steam pipelines must be protected against freezing, and the frozen foundation material from thawing, which would have a harmful effect on the stability of the pipelines and adjacent structures.	The measures indicated in Section 8 to the left are unnecessary because of the method of conveying thermal energy and the thermal condition of the conduit.
9.	The distribution system and services exert a general thermal influence on the temperature regime of the permafrost layer in the construction zone.	The distribution system and services do not exert any thermal influence on the temperature regime of the permafrost layer in the construction zone.
0.	During the operation of the lines there is always leakage of steam from the pipelines and other points (such as the services); such leakage creates a threat to the stability of adjacent buildings.	The operation of the lines does not affect the stability of adjacent structures.
1.	A great deal of earthwork and a large quantity of thermal insulation are necessary when laying pipelines; a more or less significant expenditure for the pipe itself is also inevitable.	The volume of earthwork and outlays for construction materials are reduced and thermal insulation is eliminated when laying gas pipelines and especially electrical conduits.

No.	Steam or Hot Water Pipelines	Electrical Conduits or Gas Pipelines
12.	The amortization period for the pipes of a central heating system is not more than from 10 to 15 years.	The amortization period for the pipes used in gas pipeline system is as in Section 12 to the left. Non-ferrous metal with a longer amortization period is used for electrical conduits.
13.	Rather intricate repair work is required when pipeline troubles occur.	Less intricate and less labor-consuming repair work is required when troubles with the lines are experienced.
14.	Inspection of the pipelines during operation must be carried out by a specific staff.	Approximately the same staff is used for inspection during operation.
15.	Inspections of the pipelines are continued during the summer interruption of heating in order to avoid ice blockages in the pipes.	Inspections during the summer interruption of heating are almost unnecessary for the safety of electrical conduits and gas pipelines. The systems continue to operate for lighting, supplying gas to kitchen stoves, etc., although at a reduced capacity.
16.	Temperature control in premises heated by steam is difficult. The supplying of steam to the pipelines is continued when consumers switch off heating appliances temporarily; this results in unavoidable losses and pipe freeze-up dangers.	Temperature control in premises heated by electricity or gas is maintained without difficulty. Energy losses when appliances are switched off approach zero and the condition of the lines at this time is without danger.
17.	The cost of 1,000 kilo-calories of steam at the outlet from the boiler-house is from 5 to 8 kopeks, on the average.	The cost of 1,000 kilo-calories of electrical energy in the system is from 40 to 70 kopeks, on the average. The cost of 1,000 kilo-calories of energy from gas in the system is from 10 to 40 kopeks, approximately.
18.	Kitchen stoves must be installed in dwellings; provision of a second (local) fuel-consumption system in parallel with the central heating system is therefore obligatory.	Electrical energy and gas serve for both heating and domestic needs. Kitchen stoves burning wood or coal are eliminated.

Proposed Water Distribution Systems

Water distribution lines are sometimes installed with steam tracers which provide heat; in other cases the water is preheated (before it enters the water distribution system) to a temperature sufficient to prevent the water from freezing during its entire course of travel to the consumer. When water is preheated before it enters the water distribution system, the highest temperature of the water is to be found in the first part of the system where there is a continuous and high discharge in a pipe of large diameter and where preheating is least required.

Expenditures for combating freeze-ups in water distribution systems are large and still do not eliminate troubles in the systems.

Troubles in water distribution systems are most frequently experienced during a short period of the year which is known as the critical period. The critical period does not occur at the same time for the entire system and the duration of the period is different for different sections of the system. It has different characteristics under different conditions (for example, on a service to an isolated house versus a main, on deeply-buried lines versus shallow-buried lines, zones where snow has been removed versus zones where it has been left in place, etc.).

Establishing a single thermal regime for different sections of the water distribution system with different heat exchange characteristics appears to be inexpedient. A single regime inevitably leads either to excessive heating of foundation material

in sections with a high degree of protection against cooling or to freezing of water lines in sections with a low degree of protection.

The operating regime of a water distribution system and hence the thermal regime of the system are changed when new consumers are connected up; such changes cannot be foreseen, even when the project is worked out in a very detailed and careful manner.

A more correct procedure would be to maintain a different heat regime (necessary and unavoidable because of local factors) for each section of the system; it is possible to establish various heat regimes for various critical temperatures during the design stage. The heat regime during operation can then be more accurately defined by actual measurements and observations of the operation of the water distribution system during the starting period. Observations must naturally be most carefully made on sections of the system which contain branches and, especially, at the extremities of the system. Observations in the upstream part of the system, where the water lines consist of pipes of large diameter, can either be neglected entirely or conducted on a greatly reduced scale. When making observations on water lines, the water temperature at each small section of the water distribution system must be known. The condition of the water line and the imminent danger of freezing can be predicted on the basis of the temperature of the water at various points in the system or the temperature change at a point in the system over a given interval of time and the rate of approach towards the critical temperature. Proper measures to remove imminent dangers must be taken without delay.

Methods of measuring water temperatures in pipelines are well-known and need not be dwelt upon here. Temperatures can be measured automatically. An automatic signal must be given to a central or local control point when the critical temperature is approached. New equipment is not required for measuring water temperatures in water distribution systems in permafrost regions; available equipment can be used.

When any section of the water distribution system is cooled to a temperature below the critical temperature, all that is required is to heat the pipes in this section (by means of an electrical current, for instance); this procedure is also very well-known in the practical operation of sanitary engineering utilities. Pipes must be surrounded by thermal insulation and fill when heated by means of an electrical current. Operating expenditures for a water distribution system are definitely reduced when such a method is used to combat freezing.

If the operation of heating the pipes is not to be automatic, it must be carried out by a specially-qualified crew of workers provided with the required instruments and equipment and ready to act at the first signal. Otherwise the signal of critical conditions can be given several hours or even several days before the imminent trouble occurs (progressive measurements of water temperatures being made in all sections of the water distribution system).

Sewage Collection Systems

All of the proposals concerning the construction and operation of water distribution and sewage collection systems under permafrost conditions can be applied in their entirety, to sewage collection syst

with the distinction that with sewage collection systems the greatest hazards occur at the upstream ends of the systems where fluid discharges are lowest and discontinuous. Fluid freezing dangers are reduced as more and more sections are connected to main sewers.

The present article is confined to the presentation, in an outline form, of a proposal concerned with certain changes in the installation of sanitary engineering utilities in permafrost regions; more detailed examination of the question is not made. A detailed analysis of the proposal should be conducted when designing a specific installation; the reported conclusion would certainly be reached and practical experience in the application of the above proposal would be gained and would serve as a source of information for further schemes.

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